

Progress report for NASA research grant
NAG5-11104

Trans-oceanic measurements for EOS Aqua
Validation

First Year Report

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Objectives

The objectives of this project are to use a state-of-the-art instrument on long, oceanic research cruises to make measurement of the sea-surface skin temperature (SST), boundary-layer meteorology and atmospheric state for the validation of AIRS and AMSR-E geophysical data. In addition to the directly measured SST, surface winds, atmospheric profiles of temperature and humidity, atmospheric columnar water vapor and rainfall, which can be compared to the AIRS and AMSR-E retrievals, measurements of the atmospheric and oceanic state are to be used with an accurate radiative transfer model to derive top-of-atmosphere radiances for comparison with AIRS measurements. The project includes a sub-contract to the University of Wisconsin-Madison for hardware support of the M-AERIs and joint studies of atmospheric infrared radiative transfer studies for the comparison between AIRS and M-AERI measurements of the spectra of atmospheric emission and retrieved atmospheric profiles of temperature and humidity.

First year activities

The emphasis on during the first year has been on

1. purchasing and testing a microwave radiometer that measures the atmospheric water vapor and cloud liquid water amounts. In addition to the intrinsic value of these measurements, the vertically integrated water vapor is to be used to renormalize the relative humidity profiles measured by radiosondes
2. recalibrating the M-AERI to ensure that the measurements are accurate and traceable to NIST standards
3. installing equipment on several ships for use during the initial phases of the Aqua mission
4. interacting with the AIRS Science Team and Validation Team members
5. interacting with the wider scientific community

Microwave radiometer

A Radiometrics MWR-1100 was procured through this grant and delivered to RSMAS in mid-summer, 2002. It is a dual-frequency total power radiometer, operating at 23.8 GHz and at 31.4 GHz. These two frequencies allow simultaneous determination of integrated liquid water and integrated water vapor along a selected path. Atmospheric water vapor has an emission line centered at 22.235 GHz, and to reduce the effects of pressure broadening upon the observed brightness, observations are made at the “hinge point” at 23.8 GHz, where the vapor emission does not change significantly with altitude. The radiometer was first installed on the roof of the Marine Science Center on the RSMAS Campus (Figure 1). It performed well and comparisons with GPS-derived water vapor measured by a system at Miami International Airport, about 10 miles away, showed agreement at the xx% level. The instrument was subsequently mounted on the *Explorer of the Sea* for nine weeks, and then on the Polar Sea for the trans-Pacific transit from Seattle to Sydney, Australia.

M-AERI Recalibration

The Marine-Atmospheric Emitted Radiance Interferometer (M-AERI; Minnett et al., 2001) is a Fourier-Transform Infrared Interferometric spectrometer that operates in the



Figure 1. The Radiometrics MWR-100 microwave radiometer installed for testing on the roof of the Marine Science Center on the RSMAS Campus.

range of infrared wavelengths from ~ 3 to $\sim 18\mu\text{m}$ and measures spectra with a resolution of $\sim 0.5\text{ cm}^{-1}$. It uses two infrared detectors to achieve this wide spectral range, and these are cooled to $\sim 78^\circ\text{K}$ (*i.e.* close to the boiling point of liquid nitrogen) by a Stirling cycle mechanical cooler to reduce the noise equivalent temperature difference to levels well below 0.1K . The M-AERI includes two internal black-body cavities for accurate real-time calibration. A scan mirror directs the field of view from the interferometer to either of the black-body calibration targets or to the environment from nadir to zenith. The mirror is programmed to step through a pre-selected range of angles. When the mirror is angled below the horizon the instrument measures the spectra of radiation emitted by the sea-surface, and when it is directed above the horizon it measures the radiation emitted by the atmosphere. The sea-surface measurement also includes a small component of reflected sky radiance. The interferometer integrates measurements over a pre-selected time interval, usually a few tens of seconds, to obtain a satisfactory signal to noise ratio, and a typical cycle of measurements including two view angles to the atmosphere, one to the ocean, and calibration measurements, takes about five minutes. The M-AERI is equipped with pitch and roll sensors so that the influence of the ship's motion on the measurements can be determined. The radiometric calibration of the M-AERI is done continuously throughout its use, by using two black-body targets at known temperatures. These provide two reference spectra to determine the gains and offsets of the detectors and associated electronics. The mirror scan sequence includes measurements of the reference cavities before and after each set of spectra from the ocean and atmosphere. The absolute accuracy of the infrared spectra produced by the M-AERI is determined by the effectiveness of the black-body cavities as calibration targets. The black-body cavities are copper cylinders with conical end plates, one with a circular orifice to allow the radiation to emerge. The internal walls are painted matte black and the cavity has an effective emissivity of 0.998.

Each of the pairs of black-body calibration cavities for the three M-AERIs were returned to SSEC at the University of Wisconsin-Madison during the first year of the project for refurbishment and recalibration. After return to RSMAS they were re-mounted on the M-AERIs and tested against the NIST-traceable water-bath black-body calibration targets and were found to have residual uncertainties on the 10-20mK range in the relatively transparent parts of the atmospheric transmission spectra. The calibration target itself was recently characterized using the NIST EOS TXR (Earth Observing System Transfer Radiometer) during a CEOS-sponsored Infrared Radiometer Calibration Workshop held at RSMAS with funding from NOAA-NESDIS, ESA and EUMETSAT (Rice et al., 2003).

Research cruises

The Aqua validation equipment has been installed on four ships in different climatic regimes during the first year of this project: the *Explorer of the Seas* in the Caribbean, the *Pierre Radisson* in the Canadian Arctic; the *Urania* in the Mediterranean; and the *Polar Sea* in the Pacific Ocean.

Explorer of the Seas.

The *Explorer of the Seas* is a 142,000 ton cruise liner, some 315 m in length, and is the first cruise ship outfitted with a suite of sophisticated oceanographic and atmospheric instrumentation. During construction and outfitting of the *Explorer of the Seas*, Royal Caribbean International worked with the RSMAS, NOAA-AOML, and the NSF to equip the ship with state-of-the-art instrumentation and install laboratories for oceanography and atmospheric sciences. The ship typically cruises at an average speed of 20 knots on two alternating weekly circuits round the Caribbean (Figure 2). The main sensors on the *Explorer of the Seas* are shown in Figure 3. Of particular relevance to this project for the validation of Aqua instruments are the M-AERI, the Radiometrics microwave radiometer and radiosondes (AIRS). The microwave radiometer was operational on the Explorer for 79 days, between 7/20 and 10/5 of 2002 (Figure 4), and the M-AERI was operating continuously up until September 29, when a disk crash shut the system down. When this was repaired and the system restarted, the measured spectra were very noisy; a problem that was eventually traced to a cracked Dewar and damaged detectors. The data flow was



Figure 2. The weekly cruise tracks of Explorer of the Seas. The ship sails from Miami on Saturday evenings, returning the following Saturday morning. The eastern and western tracks are sailed on alternating weeks.

INSTRUMENT LOCATION AND FUNCTIONS ABOARD EXPLORER OF THE SEAS

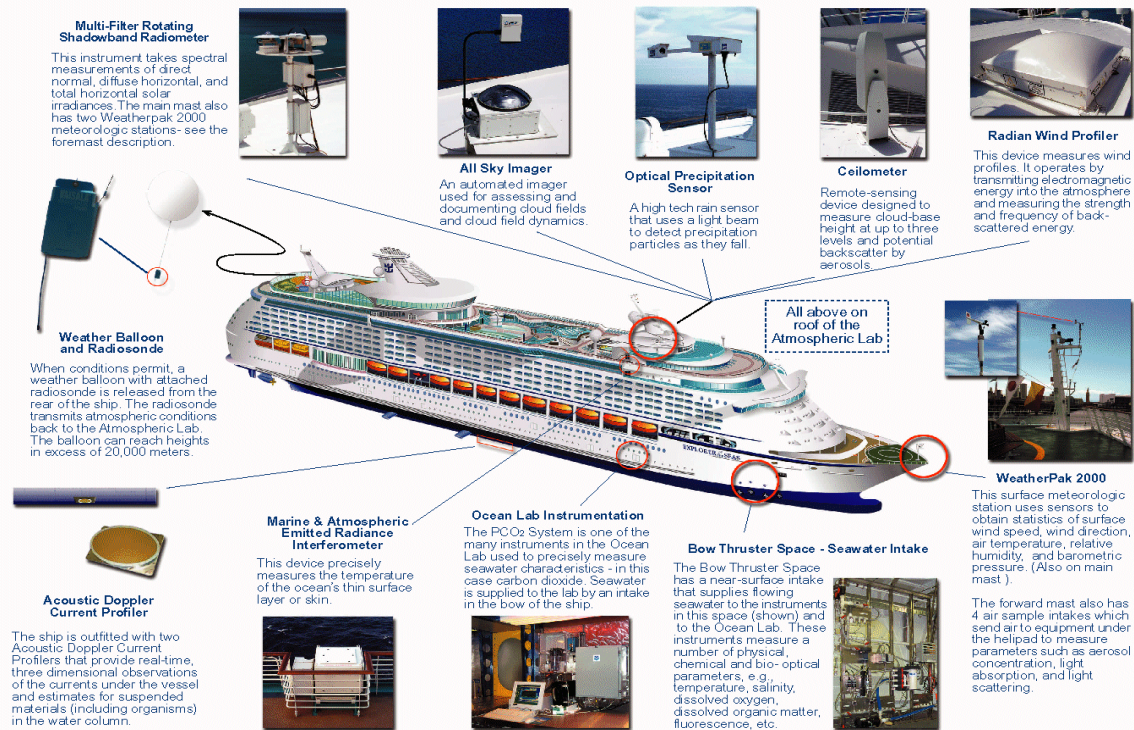


Figure 3. The main sensors routinely deployed on the *Explorer of the Seas*.
From www.rsmas.miami.edu/rccl/



Figure 4. The Radiometrics MWR-1100 microwave radiometer mounted in the roof of the Atmospheric Laboratory on *Explorer of the Seas*. The picture was taken while the ship was in the Port of Miami. Outboard of the radiometer is the Whole Sky Imager, and inboard the optical rain gauge.

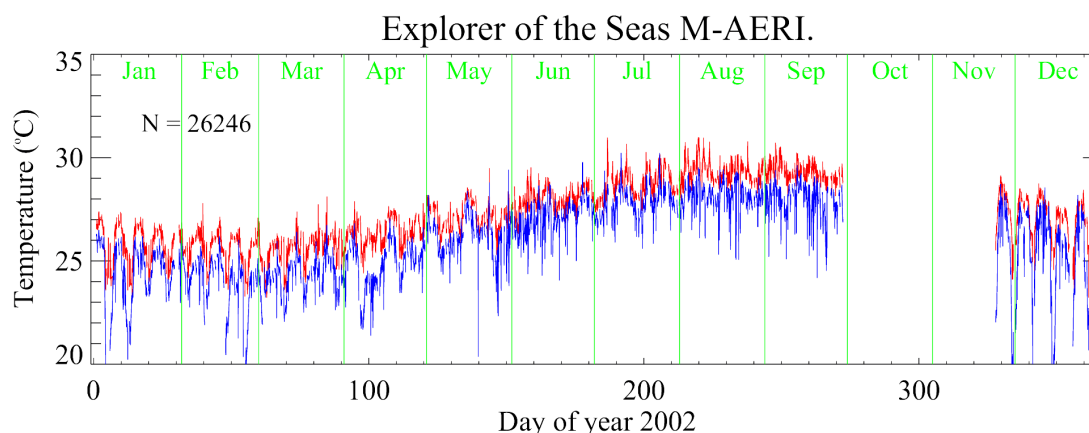


Figure 5. Measurements of skin sea-surface temperature (blue) and air temperature (red) from the M-AERI on *Explorer of the Seas* for 2002. The gap in October and November was caused by instrument failure.

resumed on November 23. The skin SST and air temperature derived from the M-AERI data for the whole of 2002 are shown in Figure 5.

Radiosonde launches from the *Explorer of the Seas* were begun on June 25, 2002, expressly in support of AIRS validation. The launches are scheduled according to the criteria set up by the AIRS Validation Project Office at JPL (Dr E. J. Fetzer). By the end of 2002, 135 radiosonde launches had been completed.

As the *Explorer of the Seas* is in permanent satellite internet contact, it is possible to transmit a subset of the data in real-time to RSMAS. These data include the standard metrological measurements, skin SST and air temperature derived from the M-AERI, and the radiosonde profiles. Some of the data is displayed in near real-time (within less than 15 minutes) on a webpage (see <http://www.rsmas.miami.edu/rccl/obs/ex-rt-obs.pl>). At the end of each day, the M-AERI temperatures and radiosonde data are written to files in netCDF and placed on an ftp server for transmission to the AIRS Validation Team at JPL.

Pierre Radisson

A berth was offered on the Canadian Coast Guard ice-breaker *Pierre Radisson* to the PI during the cruise in the Arctic Ocean off the coast of Canada. This cruise is part of a long-term, multi-disciplinary project called CASES, the Canadian Arctic Shelf Exchange Study, and provided an opportunity to gather AIRS validation data in high latitude conditions, which, because of the difficult logistics of operating in the Arctic, are very hard to obtain.

The scientific party joined the ship off Resolute, Nunavut, Canada, on September 18, 2002. The ship transited the Northwest Passage while the equipment was being installed and tested. After about a month of measurements the equipment was taken down on the passage back to Quebec City, where the ship arrived on October 26th. The following

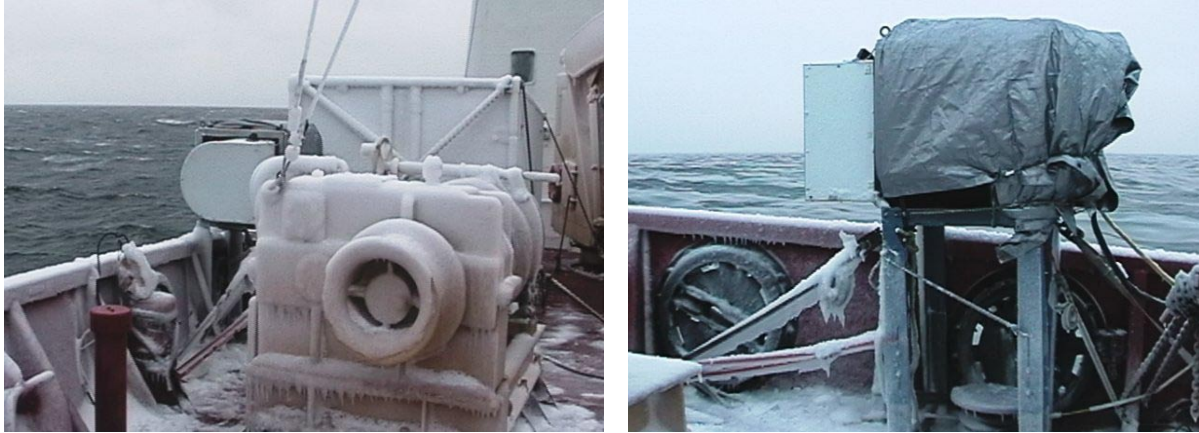


Figure 6. The M-AERI on the foredeck of the *Pierre Radisson*. The instrument was covered by a tarpaulin during storms, which coated the other foredeck equipment with snow and ice.

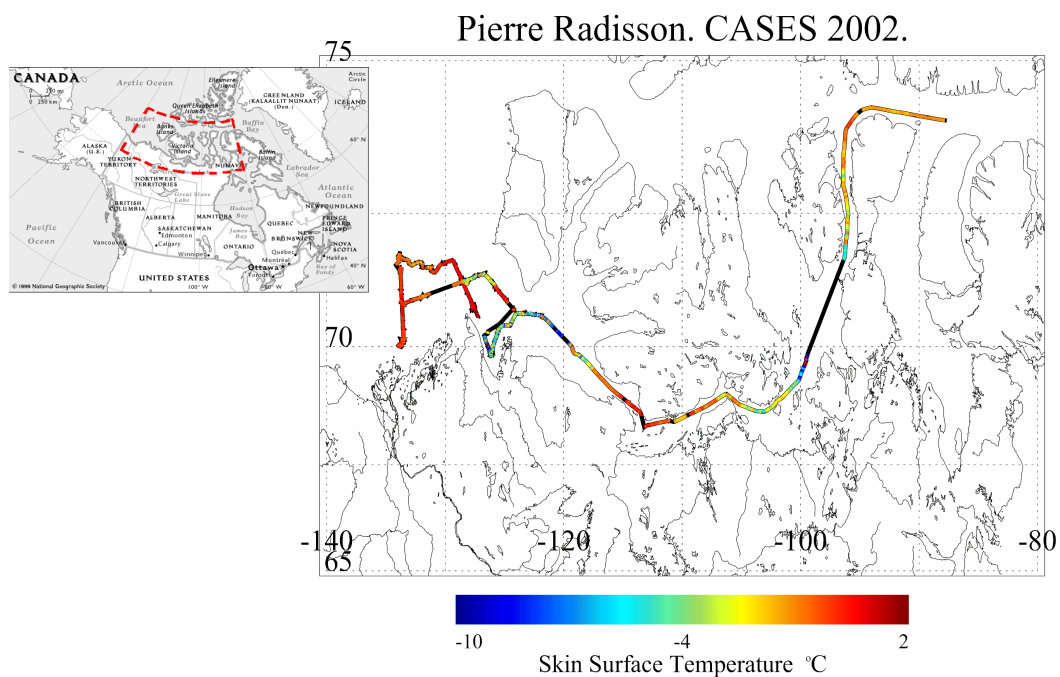


Figure 7. Study area and track of the *Pierre Radisson*, colored by surface temperature measured by the M-AERI.

several days were spent preparing the equipment for shipment back to the University of Miami. Minnett flew back to Miami on October 29th.

An M-AERI was mounted on the foredeck of the *Pierre Radisson*, on the starboard side ahead of the bow wave and bow thrusters so that the measurements taken of the sea surface at an angle of 55° from nadir were uncontaminated by the surface disturbance of

Table 1. Radiosondes launched from the *Pierre Radisson*

	Time		Location		Surface Measurements			Termination		
	Launch date and time UTC		Latitude °N	Longitude °W	T _O °C	Rh %	P _O hPa	Duration Minutes	Max height km	Min P hPa
1	25 September 2002	19:40	71.53	129.08	-2.7	89	1023.0	54.00	8.65	318.6
2	26 September 2002	5:12	71.62	130.00	-1.3	88	1023.6	73.50	15.099	118.4
3	26 September 2002	21:16	71.54	131.85	-0.9	87	1018.8	69.83	16.442	96.7
4	27 September 2002	15:18	71.62	132.18	-1.4	92	1011.4	90.00	20.029	55.1
5	27 September 2002	21:30	71.71	133.63	-1.3	92	998.5	108.50	12.405	178.3
6	30 September 2002	21:57	70.25	133.53	-0.8	83	1010.9	104.50	23.521	31.2
7	08 October 2002	0:12	71.30	128.10	-9.5	85	992.0	77.00	19.509	55.5
8	08 October 2002	8:28	71.30	127.60	-11.7	85	994.0	101.00	20.384	48.1
9	09 October 2002	12:27	71.00	135.30	-5.6	72	998.2	63.60	9.874	240.7
10	11 October 2002	12:21	70.02	126.43	-11.3	89	996.4	84.00	20.999	42.4
11	12 October 2002	20:52	70.01	125.95	-5.6	86	1018.3	66.67	11.786	187.3
12	13 October 2002	11:52	70.49	124.37	-8.2	77	1021.0	99.00	22.536	37.4
13	13 October 2002	21:37	70.64	123.35	-8.5	58	1024.0	106.00	22.516	34.9
14	15 October 2002	20:31	68.33	113.06	-5.8	85	1014.3	72.17	16.494	90.4
15	16 October 2002	10:39	68.69	103.95	-6.3	85	1022.7	54.50	10.872	214.1
16	16 October 2002	18:48	69.30	99.58	-10.0	90	1029.7	27.83	5.807	470.5
17	17 October 2002	20:00	72.84	96.22	-2.3	94	1028.4	38.00	6.311	445.7
18	20 October 2002	8:31	68.92	64.13	-0.1	86	1030.2	76.00	20.156	51.5
19	20 October 2002	16:27	66.71	60.81	-0.1	89	1028.1	83.50	21.586	41.2
20	21 October 2002	5:44	63.53	62.14	0.8	97	1024.4	33.17	8.837	304.4
21	21 October 2002	15:35	61.40	64.10	3.2	88	1020.0	26.17	6.311	440.8
22	21 October 2002	17:15	61.04	61.06	2.8	87	1018.9	74.50	21.266	43.4
23	22 October 2002	6:33	59.74	63.02	3.1	85	1019.6	83.83	22.197	37.1

the ship (Figure 6). The M- AERI operated for 26 days and a total of 2628 sets of spectra of the surface at 55° emission angle, of the atmosphere at 55° and at 0° (zenith) were taken. Figure 7 shows the track of the ship while M-AERI data were being taken. To assist in the data interpretation a time-lapse video system was installed with the camera mounted on the forward railing above the bridge, pointing down to the field of view of the M-AERI. This provides a record of the surface conditions at the times of the M-AERI measurements.

The state of the atmosphere was measured by radiosondes, generally timed to coincide with satellite overpasses. These are listed in Table 1.

Urania

A berth was offered on the Italian research vessel *Urania* during a cruise in the western Mediterranean Sea. This provided an opportunity to gather AIRS validation data in an area often influenced by aerosol-laden atmospheres. Dr. Kirk Knobelspiesse from NASA GSFC was also investigator on the cruise and took lidar measurements that will be used for aerosol characterization.

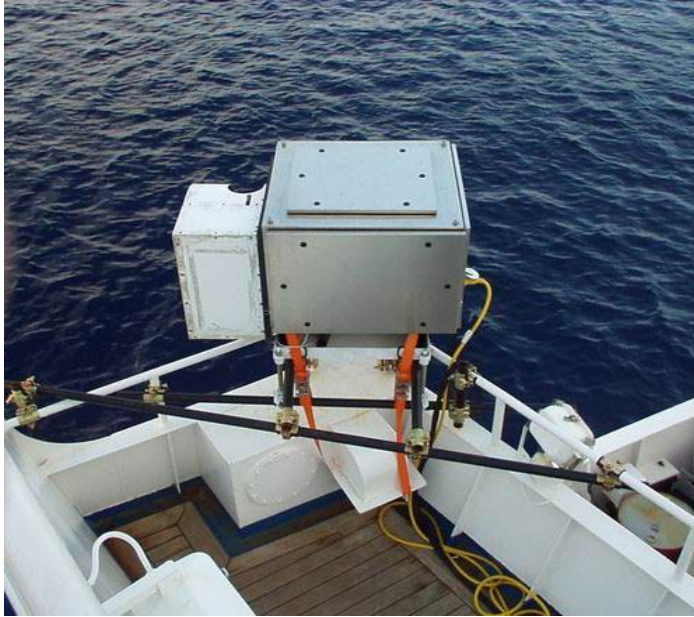


Figure 8. The M-AERI mounted on the R/V *Urania* October 10th. Dr. Szczodrak left on October 11th.

Dr M. Szczodrak of the RSMAS Remote Sensing Group, participated in the cruise and flew to Naples on September 18th to join the ship. The *Urania* sailed on September 20th heading west to the study area, where the weather conditions were so bad that all scientific activities were postponed on the grounds of safety. Validation data were taken from September 29th to October 8th. The ship returned to Livorno on October 9th and the equipment was prepared for shipment back to Miami on

The equipment mounted on the ship for *Aqua* validation included M-AERI, a surface float for measuring bulk sea-surface temperature at a depth of ~5cm, an all-sky camera, and a meteorological system, containing sensors to measure wind speed and direction, air temperature and humidity, and incident short- and long-wave radiation. The M-AERI was mounted on the railing of the *Urania* (Figure 8), on the port side so that its field of view was ahead of the bow wave so that the measurements taken of the sea surface at an angle of 55° from nadir were uncontaminated by the surface disturbance of the ship. The M-AERI operated for ten days and a total of 1026 sets of spectra of the surface at 55° emission angle, of the atmosphere at 55° and at 0° (zenith) were taken. Figure 9 shows the track of the ship while M-AERI data were being taken. The hard-hat float was deployed at most stations where the ship occupied a fixed position for oceanographic measurements to be taken. Additional sub-surface temperatures are available from the ship's thermosalinograph system.

Polar Sea

A berth was offered on the USCGC *Polar Sea* on the trans-Pacific transit from Seattle to Sydney, and Mr. K. Maillet of the RSMAS Remote Sensing Group, participated in the cruise. As on previous cruises on this ship, an M-AERI was mounted on the top of the bridge, port side. The microwave radiometer was mounted on the starboard side. The meteorological sensors were also mounted above the bridge and the radiosonde system in the geology lab at the stern so that balloons could be launched from the helicopter deck. The ship sailed from Seattle on November 4, and encountered a very severe storm in the north Pacific. On November 8 the ship took a big roll, and the bolts holding the M-AERI to the ship's railing sheared. The instrument fell to the steel deck and suffered sufficient damage that it was not repairable at sea. It was returned to RSMAS for repair from

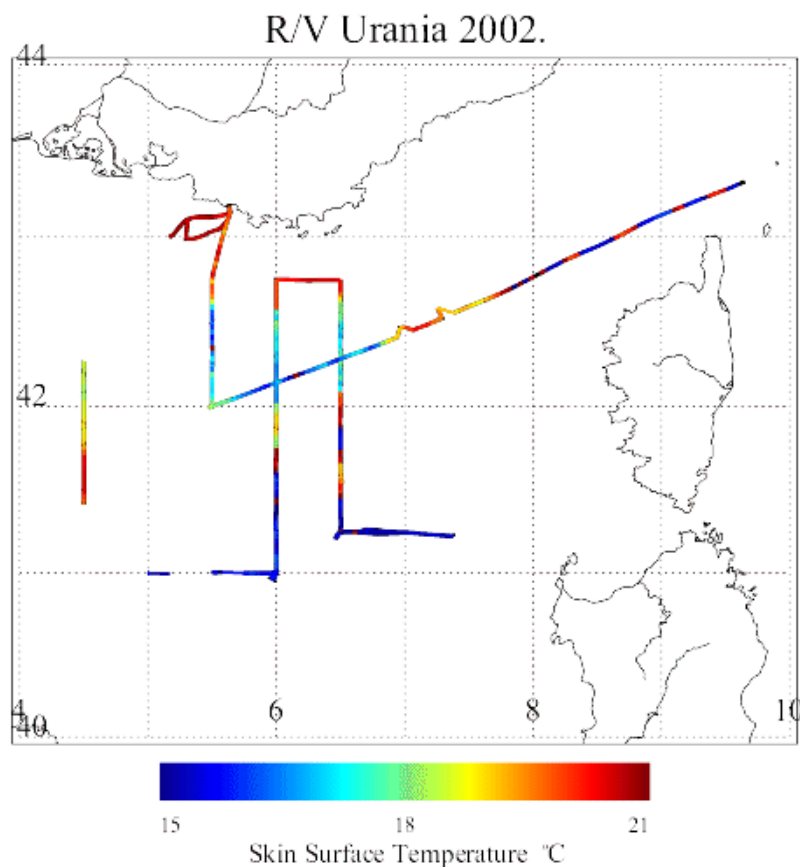


Figure 9. The track of the R/V *Urania*, colored by surface temperature measured by the M-AERI.

Honolulu, the next port of call. No other instruments were damaged. This is the first time we have suffered significant damage in over twenty M-AERI cruises, several of which have been on Polar class ice-breakers. The microwave radiometer functioned through the 25 days of the cruise, and 11 radiosondes were launched according to the AIRS validation criteria.

Interaction with AIRS Science and Validation Teams

The PI Attended the AIRS Science Team Meeting in Pasadena in November 2001 and gave a power point presentation entitled "At-sea validation of AIRS radiances." In the subsequent months, the PI collaborated with Dr Denise Hagan on the AIRS validation plan, resulting in a publication accepted for the *IEEE Transactions on Geoscience and Remote Sensing*: Hagan, D., and P.J. Minnett, 2003, AIRS Radiance Validation Over Ocean from Sea Surface Temperature Measurements. The PI has also been collaborating with Dr H.H. Auman of the AIRS Team on the radiometric validation of AIRS using comparisons between skin sea-surface temperatures measured at night by AIRS in the 'super-window' at 2126cm^{-1} and the RSMAS-derived MODIS $4\mu\text{m}$ sea-surface temperatures, which have been validated using M-AERI and drifting buoys. MODIS sea-surface temperatures, derived at RSMAS, have also been delivered to Dr W.W.

MacMillan of the University of Maryland, Baltimore County, for use in AIRS validation over the Chesapeake Bay Light Tower.

Interacting with the wider scientific community

The cruise opportunities on foreign ships have arisen out of long-standing collaborations between the PI and Professor David Barber at the University of Manitoba, Canada, for the *Pierre Radisson*, and Dr Rosalia Santoleri of the CNR Institute for Atmospheric Sciences and Climate, Rome, Italy, for the *Urania*. It is anticipated that these collaborations will continue and result in additional cruise opportunities in 2003.

The M-AERI data from the Explorer of the Seas have also been made available to the Validation Team for the Advanced Along-Track Scanning Radiometer (AATSR), flying on the European *Envisat* satellite. The AATSR project is led by Professor D. Llewellyn-Jones at the University of Leicester in the U.K.

Dr C. Rocken, of UCAR, Boulder, is refining techniques for measurements of atmospheric water vapor using GPS signals, and is collaborating with the PI by making comparative measurements on the *Explorer of the Seas*.

The PI is a member of the Science Team of the Global Ocean Data Assimilation Experiment (GODAE) High Resolution Sea-Surface Temperature Pilot Project (GHR SST-PP), which aims to facilitate the provision of accurate, high-resolution sea-surface temperature fields to the operational forecasting community and to climate researchers. The PI has been instrumental in bringing the potential of not only MODIS but also AIRS as sources of suitable, well-validated data to the awareness of this project.

Future Plans

The work in the second year will include:

1. Continuing deployment of validation instruments on the *Explorer of the Seas* and other ships as opportunities arise. This leverages other funding and both benefits from and contributes to strengthening international collaborations.
2. Continue to make the validation data sets available to the AIRS and wider community
3. Continued comparisons of AIRS, MODIS and M-AERI SSTs
4. Begin comparisons of AIRS and M-AERI infrared spectral measurements.
5. Continue collaborations with the AIRS Science and Validation Teams and with the wider scientific community.